Poster Abstract: Energy Profiling for mPlatform

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Abstract

The ability to accurately profile energy consumption is of great importance for energy management in low-power devices. This work presents a novel energy profiling architecture by combining the high-speed CPLD bus signaling capability of mPlatform with the smart TwinStar power board. By running mPlatform under different modes, we are able to utilize an MMSE estimator to analyze per-component energy consumption rates with sufficient accuracy. In our experiment, we use the profiling results to determine the working condition of individual components, as well as the hardware configuration of the sensor node.

Categories and Subject Descriptors

C.2 [**Computer-Communication Networks**]: Distributed Systems

General Terms

Energy Profiling, Energy Harvesting

Keywords

mPlatform, Ultra-capacitor, TwinStar

1 Introduction and Motivation

Energy profiling measures energy consumption of system components running at diverse power modes and operational settings. Energy profiling in sensor node is an important part in sensor network research, since the energy profile of hardware and software components determines the longevity of a sensor node. Legacy solutions can be roughly divided into two categories: (i) off-line profiling with power models, simulation or trace [1] ; (ii) online profiling with sampling or measurements [2]. On one hand, the off-line profiling methods normally assume isolated per-component energy models, which could lead to inaccurate measurements without considering (i) shared circuitry (e.g., bus), (ii) warm-up and transient energy, (iii) workload-dependency, and (iv) in-situ factors. On the other hand, most of existing online profiling methods collect only the statistics on overall energy consumption for the purpose of evaluation at the system-level.

Besides using battery for power supply, researchers are investigating the possibility for applying ultra-capacitor as energy source in a sensor node. Ultra-capacitor features almost unlimited recharge cycles, more predicable energy model and higher charge/discharge efficiency, comparing with batteries, and thus considered to be more suitable for sensor network applications. The TwinStar power board [4], developed by University of Minnesota, uses dual solar panels to harvest energy from the environment and applies ultra-capacitor as the only energy storage to power sensor nodes.

The mPlatfom [3] is designed as a modular sensornet platform by Microsoft Research, and it could dynamically reconfigure the system hardware structure to meet specific system requirements, by using a CPLD bus to interconnect multiple boards into a functional sensor stack. The structure of mPlatform can potentially be used for accurate energy profiling and accounting for sensornet applications. Based on this unique modular design of mPlatform, our main idea is to use its CPLD bus to signal the activities of individual components within each mPlatform module to an energy management unit built on TwinStar.

In the remaining part of this article, we firstly introduce the design of our energy profiling sensor node, and then describe the procedures of our experiment.

2 System Design

Figure 1 shows the augmented design for mPlatform with the energy profiling capability. We use an Energy Management Unit (EMU) on top of the mPlatform boards. EMU serves two functions: (i) it provides energy to the underlying mPlatform with a solar panel powered ultra-capacitor, similar to the structure as the TwinStar power board [4]; (ii) EMU conducts energy profiling by measuring the current through a sampling resistor (0.5 Ω). Thus the current can be measured via voltage drop on the resistor. We use the mPlatform high-speed CPLD bus to signal the active and sleep status of individual modules to a microcontroller on the EMU, and

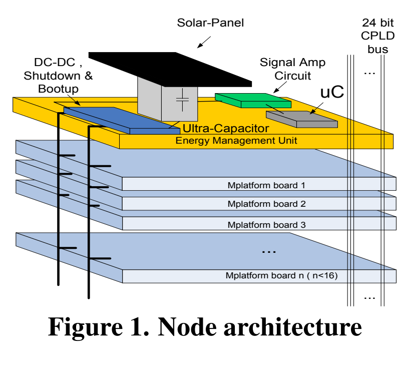

Figure 1. Node architecture

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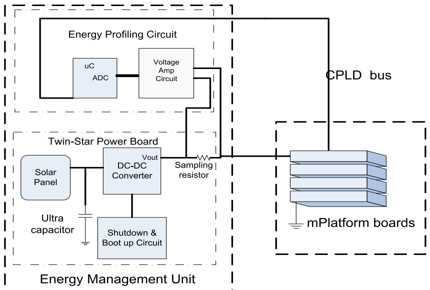
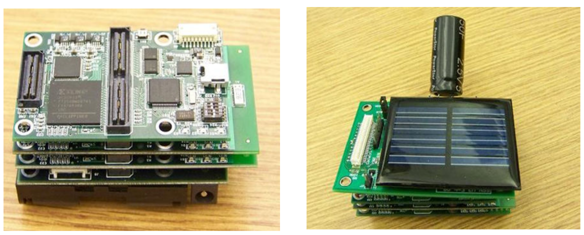


Figure 2. Circuit schematics for our sensor node



(a) (b)

Figure 3. mPlatform (a) and TwinStar power supply (b)

the corresponding energy is measured through the energy profiling circuit on the EMU. The main idea for hardware-component profiling is as follows. Let the active duration of each hardware component i at the power level j to be $t_i^j(k)$, and the total energy consumption during the kth period to be $E(k)$, then we have

$$E(k) = \sum (t_i^j(k) \times e_i^j) \tag{1}$$

where e_i^j is the unknown energy consumption of component i at the power level j. If there are totally N combinations of different components at diverse power levels, we can have a linear system with N unknown e_i^j. To solve this linear system, we shall measure e_i^j and $E(k)$ for at least N periods. Considering possible measurement errors and $E(k)$, we can use the minimum-mean-square-error (MMSE) estimator to obtain the unknown e_i^j, by using measurements of $E(k)$ from more than N sampling periods. Given the profiling results, energy accounting can be achieved by calculating energy consumption before conducting any system-level tasks.

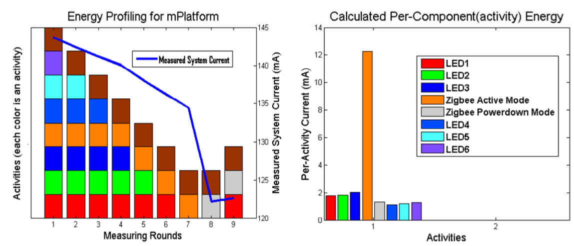
3 System Implementation

We implement the MMSE method considering the specific structure of the hardware and the operating system (OS) of mPlatform. The CoMOS OS [5] running on mPlatform is a component messaging based OS targeting mobile sensing and communication. In a mPlatform sensor node shown in Figure 1, there could be up to 14 boards stacked together and be connected by a high speed CPLD based inter-module bus. On each mPlatform board, there is a main processor (a TI MSP430 or a NXP ARM7TDMI) that communicates to a CPLD (Xilinx CoolRunner) handling the TDMA-type communication among different boards. There's also a local OS running on each module, handling messages coming from other modules. With the high speed CPLD bus (68MHz, 16-bit width [3]), we can signal the activities of individual module through the bus and record the corresponding power consumption to a master board without significant delay.

The TwinStar power board [4] is designed specifically for sensor network application, and uses solar powered ultra-capacitor to provide energy for the entire node. We place the power board on top of the node stack, as shown in Figure 1. The mPlatform modules themselves are powered by the TwinStar power board. However, in order to alleviate the observer effect: the processor on the EMU also consumes power when measuring the system power consumption. We will provide a separate power supply to the EMU.

4 Preliminary Experiment Results

We built a GUI running on a PC to give commands to the sensor node via a serial prot, for enabling/disabling individual hardware components; also, we use CC2420 radio to deliver energy information to a remote sensor node. The measured energy results are displayed on the PC.



(a) Data for 9 Rounds of Exp. (b) Per-Component Energy Est.

Figure 4. Partial energy profiling results for mPlatform

Figure 4 shows our preliminary results using our Enenrgy Management Unit(EMU) for profiling the component-level energy consumption for mPlatform; each color represents an activity (or component) of the node, such as LED on or Zigbee radio active. Figure 4(a) shows the nine rounds of experiments we run and the activities we enabled in each round, Figure 4(b) shows the calculated per-component energy cosumption. We use the system current draw to represent the energy (power) consumption, with Vcc=3.3V.

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